Estimating the Frequency of Sudden Stratospheric Warming Events back to 1850 from Surface Observations of the North Atlantic Oscillation

Daniela I.V. Domeisen, Institute for Atmospheric and Climate Science, ETH Zurich

Motivation

Sudden stratospheric warming (SSW) events can exhibit long-lasting surface impacts that promise improvements in medium-range to seasonal predictability. Their surface impact is dominated by the negative phase of the North Atlantic Oscillation (NAO). Hence, the question arises if stratospheric variability, and in particular the frequency of SSW events, can in turn be estimated from surface NAO conditions. This is especially relevant for the period before frequent upper air observations became available, while daily surface observations of the NAO date back to 1850.

Data and Methods

A station-based daily NAO time series is available from 01-Jan-1850 to 15-May-2014 [*Cropper et al.*, 2015], based on daily sea level pressure observations from stations in Iceland and the Azores. ERA-interim and ERA-40 data is used to determine the occurrence of SSW events for 1958 - 2014. The most prominent surface NAO characteristics observed after SSW events are (1) an increased persistence of the negative NAO phase, and (2) a drop from a positive to a negative NAO, which are here determined from the Cropper NAO time series.

(1) NAO persistence criterion: For days 8 - 52 after the central date of a SSW event, the NAO index averaged over this period must be negative, and the fraction of days within this period must be over 50%.

(2) NAO switch criterion: The NAO has to drop by more than 1 standard deviation between the averages over two 11-day periods that are separated by a minimum of 1 and a maximum of 19 days. The average of the surface NAO over the first (second) 11-day period has to be positive (negative).

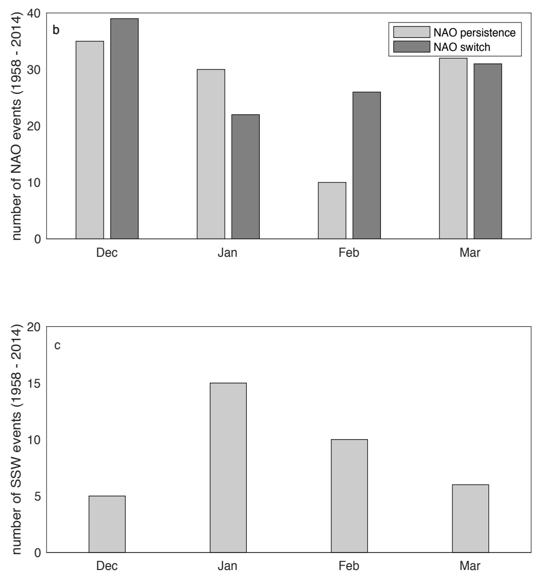

Figure 1. The total number of NAO events per winter month for (top) 1958 - 2014; (bottom) the total number of SSW events per month for 1958 - 2014.

Changes in NAO persistence after SSW events

Short persistences of 2-5 days are more common for the negative NAO phase, while persistences of 6 - 12 days are more common for the positive NAO phase (Fig. 2). After SSW events, negative NAO persistence events are more common as compared to positive NAO persistence events for persistences of 11 - 22 days. The differences between the positive and negative NAO persistence distributions are significant according to a Kolmogorov-Smirnov test at the 1% level for both the satellite-era and the full time series. The overall distribution of NAO persistence events after SSW events is significantly different from its climatology (1979-2014) at the 1% level.

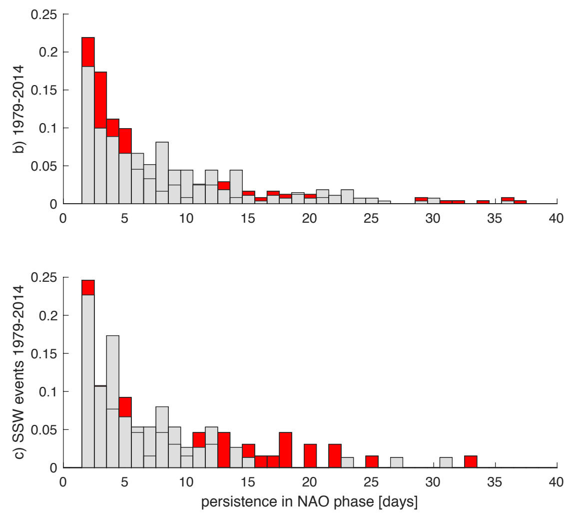

Figure 2. Histogram of the persistence [days] longer than 1 day in a positive (light gray) versus negative (red) NAO phase for winter (DJFM 1979 - 2014) for (top) the NAO time series, (bottom) the days 8 to 52 after the occurrence of a SSW event. Horizontal bars inside the gray bars indicate the height of the red bars where the gray bars are taller than the red bars. The distributions are normalized for comparison.

Event statistics

(a) NAO persistence events	number of events	events / winter
1850 - 2014 (164 winters)	308	1.88
1979 - 2014 (35 winters)	60 (following SSW: 14)	1.71 (following SSW: 0.40)
(b) NAO switch events		
1850 - 2014	365	2.23
1979 - 2014	72 (following SSW: 11)	2.06 (following SSW: 0.31)
(c) SSW events		
1979 - 2014	24 (downward: 13)	0.69 (downward: 0.37)

Table 1. Total number of events for (a) persistence events, (b) switch events, and (c) SSW events for the periods indicated in the left column for total number (middle column) and number of events per winter (DJFM) (right column). The number in brackets for (a,b) indicates the number of events that follow SSW events. The number in brackets in (c) indicates the number of SSW events with a downward impact according to Karpechko et al (2017).

For more detailed information:
Domeisen, D. I. V. (2019). Estimating the Frequency of Sudden Stratospheric Warming Events from Surface Observations of the North Atlantic Oscillation. Journal of Geophysical Research - Atmospheres. http://doi.org/10.1029/2018JD030077

Reconstruction of SSW frequency back to 1850

The frequency of downward SSW events is estimated from a linear regression on the smoothed time series of the NAO persistence events for the known part of the downward SSW time series (1979-2014). The uncertainty of the estimate (shading in Fig. 3) is estimated using a bootstrapping approach with 1000 sub-samples consisting of 30 random samples out of the 35 available years to determine the 5th and 95th percentiles of the regression coefficients.

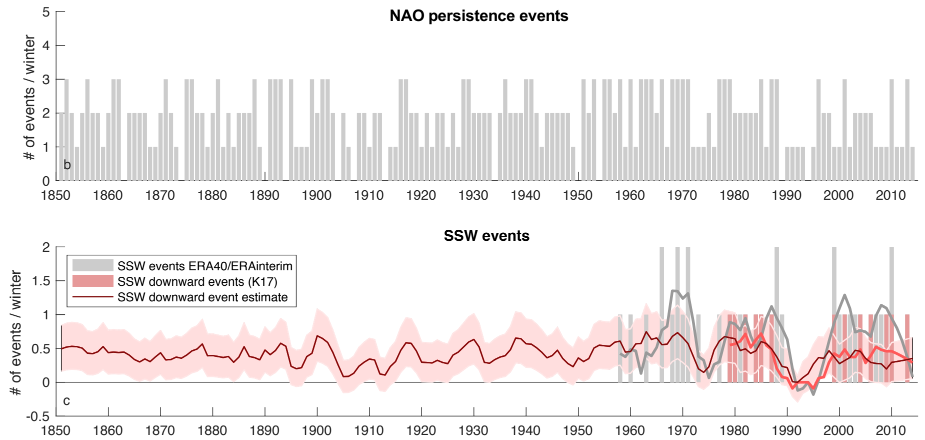

Figure 3. (top) The number of NAO persistence events per winter (DJFM) from 1850/51 to 2013/14. The indicated year corresponds to January of the displayed winter. (bottom) The number of SSW events per winter (gray bars) for a combination of ERA40 and ERA-interim data (1958 - 2014) and the number of downward SSW events classified in Karpechko et al (2017) for 1979 - 2014 (red bars). The gray and light red lines indicate the smoothed frequency of occurrence for the respective time series (underlying bars). Smoothing was applied using a Savitzky-Golay filter of degree 2 and an averaging window of 10 years. The dark red line indicates an estimate of downward SSW events (see text for details), while the shading indicates the uncertainty given by the 95th percentile.

Main findings

- **Two thirds of SSW events are followed by a surface impact** in terms of a persistently negative NAO and/or a switch to a negative NAO at the surface.
- **Winter surface NAO anomalies commonly observed after SSW events are preceded by a SSW in less than 25% of all cases**.
- The reconstructed SSW frequency time series does not exhibit a long-term trend, but changes to more decadal variability from the 1800s to the 1900s.
- The observed absence of SSW events in the 1990s coincides with the longest absence of NAO events since 1850, and **the 1990s constitute the most extreme minimum in SSW frequency in the reconstructed timeseries back to 1850**.

References

Cropper, T., E. Hanna, M. A. Valente, and T. Jónsson (2015), A daily Azores-Iceland North Atlantic Oscillation index back to 1850, Geoscience Data Journal, 2(1), 12–24.
Domeisen, D. I. V. (2019). Estimating the Frequency of Sudden Stratospheric Warming Events from Surface Observations of the North Atlantic Oscillation. Journal of Geophysical Research - Atmospheres. http://doi.org/10.1029/2018JD030077
Karpechko, A. Y., P. Hitchcock, D. H. W. Peters, and A. Schneidereit (2017), Predictability of downward propagation of major sudden stratospheric warmings, *Q. J. Royal Met. Soc.*, *104*, 30,937.